DEPARTMENT OF DEFENCE
DEFENCE SCIENCE & TECHNOLOGY ORGANISATION
DSTO

Cost-Benefit Analysis Concepts for Insensitive Munitions Policy Implementation

A. White and R.P. Parker

DSTO-GD-0230

Cost-Benefit Analysis Concepts for Insensitive Munitions Policy Implementation

A. White and R.P. Parker

Weapons Systems Division
Aeronautical and Maritime Research Laboratory

DSTO-GD-0230

ABSTRACT

Australia's Insensitive Munitions (IM) policy requires ADF Program Managers to introduce Insensitive Munitions into Service where it is "sensible, practicable and cost-effective to do so". An assessment of the cost-benefits of introducing IM is likely to require a financial analysis which differs from those normally undertaken, in that many of the benefits may be probabilistic and/or difficult to quantify. This report discusses factors applicable to IM cost-benefit analyses, and indicates some important areas which should be taken into consideration when conducting such analyses.

RELEASE LIMITATION

Approved for public release

DEPARTMENT OF DEFENCE
DEFENCE SCIENCE & TECHNOLOGY ORGANISATION
DSTO

Published by

DSTO Aeronautical and Maritime Research Laboratory
PO Box 4331
Melbourne Victoria 3001 Australia

Telephone: (03) 9626 7000
Fax: (03) 9626 7999

AR-011-169
December 1999

APPROVED FOR PUBLIC RELEASE

Cost-Benefit Analysis Concepts for Insensitive Munitions Policy Implementation

Executive Summary

Insensitive Munitions (IM) offer improved safety over those munitions currently in service through reduced likelihood of accidental initiation or reduced severity of response if accidental initiation does occur. An Australian Insensitive Munitions (IM) Policy was introduced in 1993. This policy requires IM to be introduced into Service with the Australian Defence Organisation where it is "sensible, practicable and cost-effective to do so". All further procurement of Defence explosive ordnance should meet IM criteria, subject to consideration of cost benefits. The concepts described in this paper can be used to assist in assessing whether the introduction of an insensitive variant of a weapon system is "cost-effective" as required by the Defence Instruction.

Cost-benefit analysis is a powerful method for assessing the economic viability of projects and for choosing between alternative projects. This paper briefly describes some cost-benefit concepts and considers their applicability to the types of analysis which could be used to assess the cost-effectiveness of IM. It is not intended to be a guide to conducting conventional cost-benefit analyses, for which more comprehensive texts are available; it is intended to highlight some of the unusual aspects of IM cost-effectiveness/benefit analyses, and complements the general discussion of the requirements of an Australian IM cost-benefit methodology presented previously. It also brings together concepts which may be referred to in subsequent publications on the subject.

It is concluded that in assessing the cost-benefits of IM:

- A cost-benefit analysis is preferable to a cost-effectiveness analysis.
- The analysis period should be sufficiently long (say, 20 years) to adequately indicate any long-term differences between the options.
- While tangible and quantifiable costs and benefits can be included in the analysis, note should be taken of intangible or unquantifiable factors that may affect the ultimate decision. These should include any loss or hazard to human life or health.
- Discounting is probably not a significant factor in assessing the introduction of IM unless there is a significant difference in the expected expenditure patterns over time between the options.
- Probabilities and risks must be taken into account in the assessment. Preferably sensitivity analyses and Monte Carlo simulations should be conducted to assess the effects of variations in the input parameters.

Contents

1. Introduction

Insensitive Munitions (IM) offer improved safety over those munitions currently in service through reduced likelihood of accidental initiation or reduced severity of response if accidental initiation does occur. An Australian Insensitive Munitions (IM) Policy [1] was introduced in 1993. This policy requires IM to be introduced into Service with the Australian Defence Organisation where it is "sensible, practicable and cost-effective to do so". All further procurement of Defence explosive ordnance should meet IM criteria, subject to consideration of cost benefits.

Cost-benefit analysis is a powerful method for assessing the economic viability of projects and for choosing between alternative projects. This paper briefly describes some cost-benefit concepts and considers their applicability to the types of analysis which could be used to assess the cost-effectiveness of IM. It is not intended to be a guide to conducting conventional cost-benefit analyses, for which more comprehensive texts [2, 3] are available; it is intended to highlight some of the unusual aspects of IM cost-effectiveness/benefit analyses, and complements the general discussion of the requirements of an Australian IM cost-benefit methodology presented previously [4]. It also brings together concepts which may be referred to in subsequent publications on the subject.

1.1 Cost-benefit analysis

The over-riding concern of cost-benefit analysis, used in the economists' sense, is with assessing the benefit of projects to society as a whole [3, 5, 6]. It is a procedure for comparing alternative courses of action by reference to the net social benefits that they produce. If the net social benefit of a project is positive, it should be accepted (subject to budget restraints) and if there are several mutually exclusive alternatives, the one with the highest net social benefit should be chosen.

This global view may sometimes be overlooked for reasons of simplicity or of focus, and the analysis then strictly becomes a financial evaluation [2] or a feasibility study [7, 8]; however, it may still be referred to as a cost-benefit analysis. For example, introduction of a new Australian-made weapon system may create additional civilian jobs in manufacturing industries, but these may not be explicitly included in an assessment of the cost-benefits of the weapon system to the Defence Department. However, in the public sector, any significant consequences beyond the project-specific factors included in the analysis should always be considered and identified as unquantified and/or intangible benefits or costs [2].

1.2 Cost-benefit vs cost-effectiveness

The terms "cost-benefit" and "cost-effectiveness" are sometimes used interchangeably, and without clear definition of what is really implied by the terms. Cost, which is common to both terms, is usually fairly easy to define in dollar terms and Defence cost concepts have been discussed by Landau [9, 10]. Cost-effectiveness analysis differs from cost-benefit analysis in that the benefits are not expressed in monetary units [2], ie, it is a tool to compare alternatives on the basis of "cost per unit of effectiveness". The benefits are described in physical terms such as "lives saved", "number of targets defeated" or "tonnes of munitions stored". Cost-effectiveness analysis only provides a self-referencing ranking of projects, and so it should as far as possible be avoided when decision-makers are seeking information to aid a decision on the level of resources to allocate to a particular area [2].

There is a conceptual difficulty with attempting to determine the *cost-effectiveness* of replacing current (non-IM) munitions with insensitive munitions. We are not comparing the inherent effectiveness of the weapon system in defeating enemy targets with its cost, as we might be if we were comparing two weapons from different manufacturers. We are analysing the replacement of an existing weapon system with one that is expected to be of similar effectiveness in defeating enemy targets and may, quite possibly, be of greater cost (the effect on the cost-benefit analysis of possible differences in performance between the IM and non-IM variants are discussed in [11]). We expect benefits to come from reduced likelihood of catastrophic accidents, either due to the reduced probability of the weapon initiating unintentionally, or from the reduced consequences if the weapon does initiate unintentionally.

Another difficulty with a cost-effectiveness analysis is that, although it relaxes the requirement to value benefits in monetary terms (which may be useful when discussing benefits which are difficult to quantify), it makes more difficult the consideration of different types of benefits from several sources, eg, the loss of an aircraft on a flight line vs. loss of an explosive storehouse in a storage facility. Of course, our units of effectiveness could be the expected savings (dollars) in losses of materiel from unintentional accidents which leads us back to a cost-benefit analysis.

On the other hand, the concept of a benefit in Defence is less easily defined and quantified than in the commercial world. It is difficult to define the benefits that accrue from defence expenditure in accounting terms as there is no monetary profit. As a result, in relatively simple cases where there is only one major type of benefit that can be used as a measure of effectiveness, it may be preferable to conduct a *cost-effectiveness* analysis rather than a *cost-benefit* analysis. However, in complicated cases where there are several different types of benefits, there is no choice but to perform a full cost-benefit analysis so that the different types of benefits can be reduced to a common denominator, ie, money.

2. Cost-Benefit Analysis Concepts

2.1 Analysis period

The period over which the costs and benefits will be assessed must be determined. The period must begin sufficiently far in the future so that the analysis can be completed and discussed and policy decisions made before the commencement of the period, and the analysis period should extend to the end of the useful life of all the options considered [9]. The useful life of a weapon system or munition may be limited by one or more of several criteria as discussed in [11].

In a conventional business cost-benefit analysis, the analysis period will generally end at a set time or with the expiration of the life of the option with the shortest expected life; the residual (discounted - see below) value of the options at the end of the analysis period reflecting their remaining life. Political and technological forecasts become increasingly uncertain with increasing time of projection [9]; however, the longer the costing period, the lower is the residual value of the assets at the end of the period, which helps to diminish the effect of uncertainty in the forecasts.

The period for the cost-benefit analysis of an IM option is likely to be considerably longer than the several years (rarely more than five) used in the cost-benefit analysis of many projects. Since weapon systems and munitions generally have relatively long lives, an IM cost-benefit analysis is likely to cover a period of 20 years or more. Within this period, the life of individual munitions for a weapon system may expire before that of the system. This should not be used as a rationale to reduce the analysis period, rather, resupply of munition items should be included as a cost through the analysis period. It should also be noted that short period IM cost-benefit analyses are unlikely to be required for systems which are nearing the end of their life, since the DI(G) [1] states that, for existing systems, introduction of IM is to be conducted during routine replenishment or refurbishment of stocks and such replenishment/refurbishment will not be occurring for weapon systems/munitions which are being phased out of service.

2.2 Tangible costs and benefits

Tangible costs and benefits are those which can be readily quantified and are realisable. Conventionally, tangible costs are divided into two categories [10]:

- **capital investment:** one-off costs including such items as research, development, evaluation, equipment, initial provisioning of spares, new works and housing, initial outfit of stores and ammunition and initial training of personnel. The capital investment may not be all incurred in the first year, as installation of a particular system may take several years with different amounts of expenditure in each year.
- **recurring costs:** costs incurred year to year during the operation of the equipment. Includes direct recurring costs such as pay and allowances for personnel, materiel consumed in use and support services and indirect recurring costs (overheads).

This division of tangible costs may not be appropriate for all aspects of IM cost-benefit analyses, particularly as some costs are of a probabilistic nature (see below). Nevertheless, particularly during the data gathering phase of an IM cost-benefit analysis, both areas should be considered. Benefits typically start to be realised some time after the initial expenditure.

2.3 Intangible costs and benefits

In an similar manner to tangible costs, intangible costs may also be incurred initially or in an ongoing manner. Intangible costs and benefits can also be divided into two further categories:

- **quantifiable:** although some costs and benefits may be quantifiable, they may still be not be tangible. For example, 20 man-years of effort saved across a base does not mean that the size of the base can be reduced by 20. It may be that the 20 man-years are distributed across personnel or in time such that this reduction cannot be realised. However, the benefit should be felt in other ways, such as 20 man-years of effort available to do other things that were not done before. It is a moot point whether these quantifiable intangibles should be included in a quantitative cost-benefit analysis - although the effects should be observable, the actual value placed on the effect may not be realisable.
- **not quantifiable:** many intangible costs and benefits are not quantifiable. Here, social, moral and political factors may be involved. It is frequently these that will decide the path taken, despite the outcome of the quantitative cost-benefit analysis.

2.4 Time dependence of values and measures of cost-benefit

Conventional business cost-benefit analyses take into account the time-dependency of the value of costs and benefits by applying discount rates to both costs and benefits (Appendix A). Discounted values are used to calculate various parameters which indicate the overall cost-benefit (or otherwise) of a project. These parameters, described in more detail in Appendix B, include Net Present Value, Benefit to Cost Ratio, Return on Investment, Internal Rate of Return and Payback Period.

Discounting may not have a significant effect in a cost-benefit analysis if the options under examination have similar spreads of expenditure [10] as may be expected if an IM variant replaced a non-IM one. Also, the effect of discounting is often smaller than the uncertainties in the estimates of the costs themselves. Consequently, for a cost-benefit analysis of the introduction of IM, it is probably sufficient to assume that discounting factors for the IM variant are the same as those of the current munition because the main factors influencing these factors (inflation and interest rates) will be similar for both. There may be some difference between the variants if the time-dependence of costs of some IM components (eg explosive filling) is expected to be significantly different to those of the current variant.

2.5 Valuation of human life

Reduction/increase in the risk of loss of human life should be considered in assessing any Defence project involving munitions. If this factor is to be incorporated into a cost-benefit analysis, the value of a human life must be established. The valuation of human life and disability is also an important concept in many other areas such as health, insurance and accident injury prevention [8], however there is little consensus and the values obtained vary greatly, depending on the method used and the purpose for which the estimate was obtained. Some approaches taken to the valuation of human life are described in Appendix D and the results indicate that the estimated costs for a human life generally varies in order of magnitude from about $\$10^5$ to about $\$10^7$, depending on the method used to estimate the value and the anticipated cause of the fatality.

In Defence, the value of a particular human life to the community may vary depending on the situation. For example the life of a skilled fighter pilot in a wartime tactical situation may be a greater loss to the community than if he were lost during peacetime exercises. However, during wartime, loss of combat personnel is more expected, whereas the community demands that the risk during peacetime be effectively zero.

The introduction of IM is expected to reduce the probability of loss of (friendly) human life in both peacetime and wartime. This reduction can be estimated in tandem with the cost-benefit analysis, however rather than attempting to place a dollar value on it, it is probably best left as a semi-quantified intangible, which can then be presented to the decision-makers with the cost-benefit analysis so that informed decisions can be made.

2.6 Expert judgement

Where they are not available directly, experts may be asked to make informed judgements on the value of costs and benefits. This approach may be used to measure intangible costs and benefits and is especially useful when the problem is so complex that it is beyond the scope of the analyst to collect enough data to present a meaningful analysis. For example, the value of a ship is not just the monetary cost of the ship, materiel and lives onboard. Its value will depend on many factors including the likelihood of combat, tactical situations likely to be encountered and the value of other ships in the fleet. A survey of experts could be used to estimate the value of that ship to the overall fleet.

While this method appears very powerful, in practice it appears to be generally applicable only to obtain a ranking or, at most, a relative measure of value. For example, several experts may be asked to rank the types of ship in the fleet on the basis of value in a particular scenario. These individual rankings can then be statistically checked for agreement between the various experts and, if in agreement, totalled to give an estimate of the "true ranking" [12]. Alternatively, the ship types may be compared on a pair by pair basis, which is more sensitive and discriminating [12]. In this analysis, the expert may be required to choose, for each possible pairing of ships, the ship with the higher value. The results from this process can again be checked for agreement between the judges and used to estimate a "true ranking" [12]. If a sliding scale is used to choose between the ships in each pair, then a measure of relative value can be obtained, rather than just a simple ranking.

Whether a survey of the opinions of experts can be used to obtain accurate estimates of absolute values appears doubtful. However, these methods may be constructively applied to provide rankings or relative measures of intangible costs and benefits, which may be useful in ultimately making a decision. In addition, in practice, they may be the only way in which a "generally agreed" range for a variable can be arrived at.

2.7 Probability, statistics, risk and uncertainty

Probability is used when it is impossible to specify unequivocally that an event (eg, a coin toss) will result in a particular outcome (eg, come up heads). In cost-benefit analysis it is sometimes necessary to determine the probability of these outcomes so that the costs and benefits of these outcomes can be incorporated into the analysis. This leads to "expected" costs and benefits. For example, if, during the lifetime of a ship, there is a 10% probability of a fire that would cause $5M in damage (ignoring discounting and depreciation), then the "expected cost" is $500 000. This approach can be useful in decision tree analysis, where the decision to go down one branch rather than another may be influenced by the expected cost of benefit of taking that route.

Statistics uses experience from previous outcomes to predict the probability of each outcome (this is explored further in Appendix C). *Risk* generally refers to situations in which the probability of occurrence is known or can be calculated [7], eg the ship in the above example has a 10% risk of having a fire. Risks in cost-benefit analysis can be of a technical or an economic nature [7]. *Uncertainty* is used when the probability cannot be calculated, eg in one-off situations.

2.8 Analysis of uncertainty in input variables

2.8.1 Sensitivity/response analysis

A sensitivity analysis literally means an analysis to determine the sensitivity of a variable (or an optimum value of a variable) to changes in the estimate of a parameter, ie $\delta Y/\delta A$, where Y is the variable and A is the parameter under investigation [13]. In a broader sense, sensitivity analysis identifies the effect of variation in parameters on the outcome of a cost-benefit analysis (this is more properly called response analysis [13]). For example, if a discount rate of 10% has been used in an analysis, it may be varied between 5 and 15% to assess the effect on the outcome of the analysis. Sensitivity analysis can be used when there is not a probability distribution associated with the risk element or it is ignored (ie, assigning an equal probability to each value in the range over which the parameter is varied) [14]. Thus, the discount rate may be varied between 5% and 15% without analysing the expected probability of the discount rate being any one particular value. If it is found that a variation in any one factor has a significant effect on the outcome of the analysis, then that factor must be examined more carefully (eg this may lead to a closer analysis of the basis for the assumed value).

2.8.2 Monte Carlo simulation

When there is a probability distribution associated with the parameters, Monte Carlo simulation can be used. This is a multi-variate method in which random values of many analysis parameters are generated within their particular probability distributions and the result calculated. This is repeated many times, depending on the number of risky parameters to give a probability distribution for, say, the cost of a program. The average (mean, median or mode) of the distribution will give an indication of the most likely program cost and the measure of dispersion will give an indication of the confidence that can be given to the 'most likely' value [14]. In addition, as the distribution is expected to be approximately normal, about 95% of the values lie within two standard deviations of the mean. Hence, if the mean cost is $1.5M with a standard deviation of $0.1M, there is a 95% likelihood that the cost lies between $1.3M and $1.7M. The cumulative distribution can be used to indicate the probability that the cost will not exceed a particular value [14], eg 97.5% of all values lie below the mean plus two standard deviations ($1.7M in the example just given).

2.9 Assumptions

Assumptions can be used to simplify a cost-benefit analysis. If a cost or benefit is intangible or not quantifiable but must be included in the analysis, sometimes it is preferable and less misleading to incorporate it as an assumption. All assumptions used must be clearly identified to the decision-makers using the analysis.

3. Conclusions

The concepts described in this paper can be used to assist in assessing whether the introduction of an insensitive variant of a weapon system is "cost-effective" as required by the DI(G) [1]. It can be concluded from the discussion above that in assessing the cost-benefits of IM:

- A cost-benefit analysis is preferable to a cost-effectiveness analysis.
- The analysis period should be sufficiently long (say, 20 years) to adequately indicate any long-term differences between the options.
- While tangible, quantifiable costs and benefits can be included in the analysis, note should be taken of intangible or unquantifiable factors that may affect the ultimate decision. These should include any loss or hazard to human life or health.
- Discounting is probably not a significant factor in assessing the introduction of IM unless there is a significant difference in the expenditure patterns over time between the options.

- Probabilities and risks must be taken into account in the assessment. Preferably sensitivity analyses and Monte Carlo simulations should be conducted to assess the effects of variations in the input parameters.

4. References

1. Department of Defence (1993) *Insensitive Munitions*, DI(G) LOG 07-10 (1993).
2. Department of Finance (1991) *Handbook of cost-benefit analysis*, Australian Government Publishing Service, Canberra.
3. Sugden, R. and Williams, A. (1978), *The principles of practical cost-benefit analysis*, Oxford University Press.
4. White, A. and Parker, R.P. (1993), *Towards an Australian methodology to evaluate the cost-benefit of insensitive munitions*, PARARI '93, Canberra.
5. Mishan, E.J. (1982), *Cost-benefit analysis*, 3rd Ed., Allen & Unwin, London.
6. Pearce, D.W. (1983), *Cost-benefit analysis*, 2nd Ed., Macmillan, London.
7. Park, W.R. (1973), *Cost engineering analysis, a guide to the economic evaluation of engineering projects*, Wiley-Interscience, New York.
8. Monash University Accident Research Centre (1992), *Feasibility of Occupant Protection Measures*, Federal Office of Road Safety Report No. CR100.
9. Landau, C.S. (1971), *Cost analysis in defence studies* (Technical Note CSE 12), Central Studies Establishment, Canberra.
10. Landau, C.S. (1974), *Cost concepts in defence cost-effectiveness analysis*, (CSE Memorandum 22), Central Studies Establishment, Canberra.
11. White, A. and Parker, R.P. (1999), *A proposed methodology for the cost-benefit analysis of insensitive munitions for the Australian Defence Organisation*, DSTO General Document, in publication.
12. Moroney, M.J. (1957). *Facts from figures*, Penguin Books, London.
13. Jelen, F.C., ed. (1970), *Cost and Optimization Engineering*, McGraw-Hill, New York.
14. Flanagan, R.; Norman, G.; Meadows, J. and Robinson, G. (1989), *Life cycle costing - theory and practice*, BSP Professional Books, Oxford.
15. Jones-Lee, M.W. (1976), *The value of life - an economic analysis*, Martin Robertson, London.
16. Steadman. L. and Bryan, R. (1988), *The cost of road accidents in Australia*, AGPS, Canberra.

17. Landefeld, J.S. and Seskin, E.P. (1982), *The economic value of life: linking theory to practice,* American Journal of Public Health, 72 (6).

18. Usher, D. (1973), *An imputation to the measure of economic growth for changes in life expectancy,* NBER Conference on Research in Income and Wealth.

Appendix A: Discounting of Costs and Benefits

Project element costs and benefits are time-dependent, generally arising from two factors [9]:

- **inflation:** increasing (or decreasing ≡ negative inflation or deflation) costs of goods and services, including different rates for different items (eg, in the space of a year, the cost of a particular chemical may increase by 10% while the cost of a computer may decrease by 5% over the same period).
- **lost interest:** assuming inflation is zero, the future value of cash is lower than that of cash now due to the lost interest that could be gained if the cash were invested over that period. This means that it is preferable to delay outlays (costs) as long as possible and to obtain income (benefits) as soon as possible.

In economic analysis, the effects of inflation and "lost interest" are dealt with by assigning a *discount rate*, so that future costs can be compared with costs incurred today by giving both a *Present Value (PV)*.

There are two methods of assigning a discount rate:

(a) A discount rate which does not include inflation can be used and future costs and benefits are estimated in constant values (ie, assuming no inflation). Example: $1M invested in Year 2000 at 5% pa. interest will accumulate to $1.28M in 5 years ("constant value" or "in Year 2000 dollars" or "assuming zero inflation"). An equivalent way of expressing this is to say that $1.28M in 5 years (constant value) has a Present Value of $1M in Year 2000 and the discount rate (without inflation) is 5%.

(b) A discount rate including inflation can be used, in which case future costs and benefits are dealt with in current (at the time they occur, inflated) values. Example: Assuming inflation is 3% pa. (affecting the interest rate), $1M invested in Year 2000 will accumulate to $1.48M in 5 years ("current value" or "in year 2005 dollars"). Again, an equivalent way of expressing this is to say that an expenditure of $1.48M in Year 2005 (current value) has a Present Value of $1M in Year 2000 and that the discount rate (including inflation) is 8.15% (= interest rate + inflation rate + (inflation rate * interest rate)).

When assigning a discount rate, it must be made clear whether or not inflation has been included, so that appropriate costs and benefits can be used. Method (a) is simpler and may be preferred for that reason.

The Present Value concept can be formalised mathematically. If the costs and benefits for a particular option in year t are C_t and B_t respectively, the present value of the costs (benefits) of the option are given by the sum of all annual costs (benefits) with each discounted by the appropriate discount rate r_t over the term of the project T [2, 5]:

$$\text{PV(costs)} = C_0 + \frac{C_1}{1+r_1} + \frac{C_2}{(1+r_1)(1+r_2)} + \frac{C_3}{(1+r_1)(1+r_2)(1+r_3)} + \ldots + \frac{C_T}{(1+r_1)\ldots(1+r_T)}$$

$$\text{PV(benefits)} = B_0 + \frac{B_1}{1+r_1} + \frac{B_2}{(1+r_1)(1+r_2)} + \frac{B_3}{(1+r_1)(1+r_2)(1+r_3)} + \ldots + \frac{B_T}{(1+r_1)\ldots(1+r_T)}$$

If the discount rate is assumed to be constant over all future periods (= r), these expressions condense to:

$$\text{PV(costs)} = \sum_{t=0}^{T} \frac{C_t}{(1+r)^t} \qquad \text{PV(benefits)} = \sum_{t=0}^{T} \frac{B_t}{(1+r)^t}$$

The expression $1/(1+r)^t$ is known as the discount factor. Standard tables are available for various discount rates over a number of years [2]. It can be seen from the discussion above, that as the discount rate increases, it becomes more attractive to pay costs later and receive benefits earlier. It should be noted that the discount rate for benefits may not be the same as that for costs.

Discounting may not have a significant effect in a cost-benefit analysis if the options under examination have similar spreads of expenditure [10]. Also, the effect of discounting is often smaller than the uncertainties in the estimates of the costs themselves.

Other factors must also be considered. If the systems under consideration have the same expected lives, whole of life costing or life cycle costing can be used [9, 14]. However, if the expected lives differ, residual values at the end of the analysis period must be estimated. This residual value may reflect the remaining life of the item in its current capacity as described above, or its sale value, either for reuse or for scrap. The residual value assigned to the equipment is the maximum of the possible options [9]. Alternatively, the problem may be thought of as one of depreciation.

Costs incurred up to the time of the analysis are generally considered "sunk", ie they have already been spent and are unrecoverable, except for any salvage value or opportunity cost. *Opportunity cost* is the cost of foregoing the best alternative use for a resource [2, 9]. For example, the value of a building in a cost-benefit analysis is not the historical costs of construction and maintenance, but the value of the building in its most cost-effective role. For example, the financial costs of a munitions factory are 'sunk costs' if it has no alternative use; however if it does have an alternative use (eg as a car factory) which gives it a value much larger than its depreciated historical value, then it is this value which represents the opportunity cost.

Appendix B: Measures of Cost-Benefit

B.1. Net Present Value (NPV)

Combining the expressions for present values of costs and benefits from Appendix A leads to the expression for Net Present Value (NPV) of a project [2]:

$$\text{NPV} = \sum_{t=0}^{T} \frac{(B_t - C_t)}{(1+r)^t}$$

NPV is probably the most useful measure of the quantitative aspects of cost-benefit. Subject to budget constraints, consideration of intangibles and distributional issues, a project is acceptable if the NPV is equal to or greater than zero.

B.2. Benefit to Cost Ratio (BCR) and Return on Investment (ROI)

The benefit to cost ratio (BCR) is the ratio of the present value of benefits to the present value of costs [14], ie (assuming a constant rate of discounting):

$$\text{BCR} = \frac{\text{PV(benefits)}}{\text{PV(costs)}} = \frac{\sum_{t=0}^{T} \frac{B_t}{(1+r)^t}}{\sum_{t=0}^{T} \frac{C_t}{(1+r)^t}}$$

The BCR takes account of all cash flows and the time value of money, and is related to the NPV [14]:

$$\text{BCR} = \frac{(\text{NPV} + \text{PV(costs)})}{\text{PV(costs)}} \quad \text{or} \quad \text{BCR} = \frac{\text{PV(benefits)}}{(\text{PV(benefits)} - \text{NPV})}$$

BCR is of limited use by itself as there is no indication of the absolute magnitude of the benefits and costs, eg a BCR of 5 does not indicate whether the ratio of benefits to costs is \$5/\$1 or \$25M/\$5M.

The return on investment (ROI) is the ratio of all the benefits to all the costs. ROI also has limited value in isolation as it does not take account of the time value of money (discounting).

B.3. Internal Rate of Return (IRR)

The Internal Rate of Return (IRR) is the discounting rate (r) which gives an NPV of zero [5], ie:

$$\sum_{t=0}^{T}\frac{(B_t - C_t)}{(1+r)^t} = 0$$

This is the required rate of return (interest rate) to break even, ie when the benefits exactly compensate for the costs. Thus if an IRR for a project is 10%, then another project or investment with a higher rate of return would be preferable (on an economic basis) to undertaking this project.

B.4. Payback period

The payback or payout period is the number of years for the benefits of a proposed project to repay the costs incurred [7]. Although this may be useful for projects where there is some risk, eg if technology advances are expected to make the project redundant after a certain period, it should not be used alone as a measure of investment worth as it has several shortcomings [7]: it overemphasises the importance of early cash returns, it ignores the economic life of a project and it does not consider net benefits after the payback period.

Appendix C: Accident Probabilities

Infrequent random events, such as accidents, follow a Poisson distribution. The Poisson distribution is described by the equation:

$$P(X = x) = p_x(\lambda) = \frac{e^{-\lambda} \times \lambda^x}{x!} \qquad x = 0,1,2,....$$

where λ is the mean number of accidents per time period considered and P(X = x) is the probability that there will be x accidents in that time period.

For example, if the mean accident rate is one accident every ten years, the probability of two accidents in the next ten years is:

$$P(X = 2) = p_2(1) = \frac{e^{-1} \times 1^2}{2!} = 0.184$$

The probability that there will be "an accident" in the time period (ie, one or more accidents) is given by P(X > 0) = 1 - P(X = 0) where the probability of no accidents in the time period, $P(X = 0) = e^{-\lambda}$ (Table C1). For example, if the mean accident frequency λ is one accident per year, the probability of an accident in any particular year will be about 63%. It can be seen that as λ decreases, P(X>0) approaches λ, and for small values of λ, the probability of an accident is approximately equal to λ.

Table C1: Relationship between mean number of accidents (λ) and probability of an accident (P(X>0)) in a particular time period.

λ	P(X=0)	P(X>0)
1.0000	0.36788	0.63212
0.10000	0.90484	0.095163
0.010000	0.99005	0.0099502
0.0010000	0.99900	0.00099950
0.00010000	0.99990	0.000099995

Appendix D: Approaches to Valuation of Human Life

This subject is important in many areas of economic analysis and so is dealt with in detail in most texts discussing cost-benefit analysis and at least one text is totally devoted to this subject [15].

Some methods used for the valuation of human life are described below. Other methods include using losses accruing to others only and using a social measure of worth [5].

D.1. Human Capital

The most common method [5] of calculating the worth of a human life in monetary terms is to calculate the discounted expected loss in future earnings upon a persons death:

$$L = \sum_{T=\tau}^{\infty} Y_t P_\tau^t (1+r)^{-(t-\tau)}$$

where:

L	=	loss to the economy
Y_t	=	expected gross earnings of the person during year t
$P^t{}_\tau$	=	probability in the current year (τ) of the person being alive in year t
r	=	rate of discount during year t.

No allowance is generally made for suffering and/or bereavement of family [5]. Another problem with this approach is that it places no value on the life of people not in the workforce [2].

One estimate using the human capital approach, obtained for the purposes of quantifying the cost of road accidents in Australia, estimates the value of human life at \$400 000 (1985 dollars) [16, cited in 2]. This value reflects the average income of the victims of fatal road accidents and also attempts to include unemployment and family and community losses [2].

D.2. Required Compensation

This approach uses the increase in wages required to employ workers in occupations which involve a higher than normal probability of death [2]. This approach also has several failings, including the possibilities that the workers' perception of the risk may not be the actual risk and that wages will not reflect the increased risk of death if there is significant unemployment [2]. Five studies using this method gave values ranging from $277 000 to $5.9M (1977 $US) [17, cited in 2].

D.3. Willingness to Pay

This approach uses the amount that individuals are willing to pay to achieve a reduced risk of death. Three methods are given in [2]:

- willingness to pay for protection devices, eg smoke detectors or seat belts. Four studies gave values in the range $101 000 - $355 000 (1977 $US [17, cited in 2]).
- willingness to pay for a degree of reduction in risk (survey approach). Several cases include [17, cited in 2] which gave quantitative estimates (presumably 1977 $US) of the value of human life:
  - willingness to pay for a coronary unit to reduce the risk of death from heart attack ($38 000).
  - willingness to pay for reduced risk of airline related deaths ($8.4M).
  - willingness to pay for reduced risk of death from cancer ($1.2M).
- willingness to pay linked to human capital approach. This approach gives values of life about three times as high as those calculated using the human capital approach [16, 17, cited in 2].

Other values for human life in the civilian arena range from $US 34 000 derived from hazard pay for miners to work underground to $US 472 000 from the valuation of the cost of aeroplane accidents (1973 dollars) [18 cited in 15] . The value of the life of a military pilot is $US 270 000 when derived from instructions on when to crash-land their aircraft and $US 4.5M when derived from the decision to produce ejector seats (1973 dollars) [19 cited in 15].

DISTRIBUTION LIST

Cost-Benefit Analysis Concepts for Insensitive Munitions Policy Implementation

A. White and R.P. Parker

AUSTRALIA

DEFENCE ORGANISATION

Task Sponsor President - Australian Ordnance Council

S&T Program

Chief Defence Scientist
FAS Science Policy
AS Science Corporate Management
} shared copy

Director General Science Policy Development
Counsellor Defence Science, London (Doc Data Sheet)
Counsellor Defence Science, Washington (Doc Data Sheet)
Scientific Adviser to MRDC Thailand (Doc Data Sheet)
Scientific Adviser Policy and Command
Navy Scientific Adviser (Doc Data Sheet and distribution list only)

Scientific Adviser - Army (Doc Data Sheet and distribution list only)

Air Force Scientific Adviser
Director Trials

Aeronautical and Maritime Research Laboratory
Director
Chief of Weapons Systems Division
Research Leader Joint and Intelligence
Head Propulsion Systems Technology
Head Explosives
Head Pyrotechnics
Task Manager/Author(s):
Dr A. White (5 copies)
Mr R.P. Parker

DSTO Library and Archives
Library Fishermans Bend
Library Maribyrnong
Library Salisbury (2 copies)
Australian Archives
Library, MOD, Pyrmont (Doc Data sheet only)
US Defense Technical Information Center, 2 copies
UK Defence Research Information Centre, 2 copies
Canada Defence Scientific Information Service, 1 copy
NZ Defence Information Centre, 1 copy
National Library of Australia, 1 copy

Capability Development Division

Director General Maritime Development
Director General Land Development
Director General C3I Development (Doc Data Sheet only)
Director General Aerospace Development (Doc Data Sheet only)

Army

ABCA Standardisation Officer, Puckapunyal, (4 copies)
SO (Science), DJFHQ(L), MILPO Enoggera, Queensland 4051 (Doc Data Sheet only)
NAPOC QWG Engineer NBCD c/- DENGRS-A, HQ Engineer Centre Liverpool Military Area, NSW 2174 (Doc Data Sheet only)

Support Command Australia

DJALO, Defence Establishment, Orchard Hills, NSW, 2748

Intelligence Program

DGSTA Defence Intelligence Organisation
Manager, Defence Intelligence Organisation-Information Centre

Corporate Support Program

OIC TRS, Defence Regional Library, Canberra

UNIVERSITIES AND COLLEGES

Australian Defence Force Academy
Library
Head of Aerospace and Mechanical Engineering
Senior Librarian, Hargrave Library, Monash University
Librarian, Flinders University

OTHER ORGANISATIONS

NASA (Canberra)
AGPS

OUTSIDE AUSTRALIA

ABSTRACTING AND INFORMATION ORGANISATIONS

Library, Chemical Abstracts Reference Service
Engineering Societies Library, US
Materials Information, Cambridge Scientific Abstracts, US
Documents Librarian, The Center for Research Libraries, US

INFORMATION EXCHANGE AGREEMENT PARTNERS

Acquisitions Unit, Science Reference and Information Service, UK
Library - Exchange Desk, National Institute of Standards and Technology, US
NATO Insensitive Munitions Information Center (2 copies)

SPARES (5 copies)

Total number of copies: 57

Page classification: UNCLASSIFIED

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION
DOCUMENT CONTROL DATA

1. PRIVACY MARKING/CAVEAT (OF DOCUMENT)

2. TITLE Cost-Benefit Analysis Concepts for Insensitive Munitions Policy Implementation	3. SECURITY CLASSIFICATION (FOR UNCLASSIFIED REPORTS THAT ARE LIMITED RELEASE USE (L) NEXT TO DOCUMENT CLASSIFICATION) Document (U) Title (U) Abstract (U)
4. AUTHOR(S) A. White and R.P. Parker	5. CORPORATE AUTHOR Aeronautical and Maritime Research Laboratory PO Box 4331 Melbourne Vic 3001 Australia

6a. DSTO NUMBER	6b. AR NUMBER	6c. TYPE OF REPORT	7. DOCUMENT DATE
DSTO-GD-0230	AR-011-169	General Document	December 1999

8. FILE NUMBER	9. TASK NUMBER	10. TASK SPONSOR	11. NO. OF PAGES	12. NO. OF REFERENCES
9505/9/121	JNT 98/021	PAOC	16	18

13. DOWNGRADING/DELIMITING INSTRUCTIONS	14. RELEASE AUTHORITY
	Chief, Weapons Systems Division

15. SECONDARY RELEASE STATEMENT OF THIS DOCUMENT

Approved for public release

OVERSEAS ENQUIRIES OUTSIDE STATED LIMITATIONS SHOULD BE REFERRED THROUGH DOCUMENT EXCHANGE, PO BOX 1500, SALISBURY, SA 5108

16. DELIBERATE ANNOUNCEMENT

No Limitations

17. CASUAL ANNOUNCEMENT Yes

18. DEFTEST DESCRIPTORS

Insensitive munitions, benefit cost analysis

19. ABSTRACT

Australia's Insensitive Munitions (IM) policy requires ADF Program Managers to introduce Insensitive Munitions into Service where it is "sensible, practicable and cost-effective to do so". An assessment of the cost-benefits of introducing IM is likely to require a financial analysis which differs from those normally undertaken, in that many of the benefits may be probabilistic and/or difficult to quantify. This report discusses factors applicable to IM cost-benefit analyses, and indicates some important areas which should be taken into consideration when conducting such analyses.

Page classification: UNCLASSIFIED